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ULTRASOUND EXPOSURE IN THE WORKPLACE

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ULTRASOUND EXPOSURE IN THE WORKPLACE

This publication is intended as a source of information for occupational health and safety committees and others interested in understanding and reducing the risk of ultrasound exposure in the workplace.

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1. INTRODUCTION

The use of ultrasound in industry, science and medicine is considerably widespread. Industrial uses of ultrasound include ultrasonic cleaning, welding, impact grinding, drilling, atomizing, and material testing. Excessive exposure to high intensity ultrasound can cause a variety of adverse health effects.

This publication summarizes the possible health hazards of industrial ultrasound exposure and describes methods for measuring and ways to control ultrasound exposure in the workplace.

2. WHAT IS ULTRASOUND?

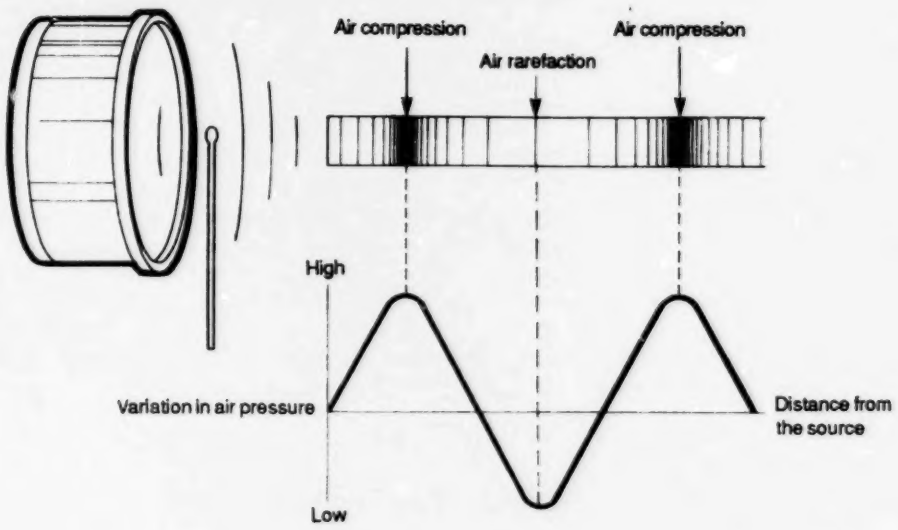
Ultrasound is a kind of inaudible sound. The only difference between ultrasound and the sound that we hear is the frequency of vibration or the number of wave cycles a source produces per second. People can hear sounds within only a certain narrow range of frequencies--other frequencies are either too low (infrasound) or too high (ultrasound). An ultrasound source sends a far greater number of wave cycles per second compared to a source of audible sound (see figure 1).

Ultrasound can travel through gases, liquids and solids. The intensity decreases as ultrasound waves travel farther from the source. Just like sound waves, ultrasound waves can be absorbed, transmitted or reflected when they impinge on a medium. Impenetrable materials such as plywood and Plexiglas stop ultrasound much more efficiently compared to audible sound. Ultrasound can pass through small openings.

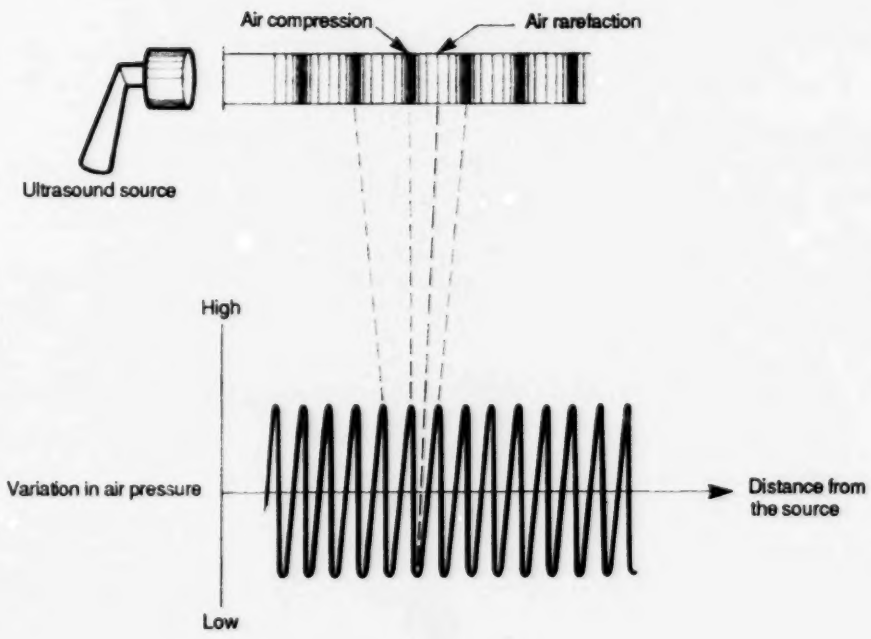
3. WHAT ARE THE UNITS OF MEASUREMENT?

Frequency

We measure frequency in units of hertz (Hz). One hertz equals one wave cycle per second, one kilohertz (kHz) equals one thousand hertz, and one megahertz (MHz) equals one million hertz. The frequency range of audible sounds is considered to be 20 Hz to 20 kHz. The upper limit of audible frequency varies from one person to another. Most people can hear up to about 16 kHz. Industrial ultrasound devices operate from about 16 kHz to about 30 MHz.



(a) Sound waves



(b) Ultrasound waves

Figure 1 - Sound and ultrasound waves

Pressure Level

It is common to express the intensity of ultrasound as sound pressure levels in units of decibels (dB). Decibel is a logarithmic scale that measures the ratio of pressure fluctuations in the air resulting from the passage of ultrasound with respect to a reference pressure.

Because is it logarithmic, the decibel scale requires special mathematical techniques for adding and subtracting decibel levels. For every doubling of the sound pressure, the sound pressure level increases by 6 dB. For every doubling of the ultrasound energy, the sound pressure level increases by 3 dB. For every tenfold increase in ultrasound energy, the sound pressure level increases by 10 dB.

Power Output

We measure the power output of an ultrasound source in watts (W). The amount of ultrasound energy passing per second through an area is measured in units of watts per square meter (W/m^2) or watts per square centimeter (W/cm^2). It is convenient to give the power output of low power ultrasonic equipment in units of milliwatts (one thousandth of a watt) or milliwatts per square centimeter (mW/cm^2).

$1\ mW/cm^2 = 10\ W/m^2$
$1\ W/cm^2 = 1000\ mW/cm^2$

4. WHAT ARE THE OCCUPATIONAL SOURCES OF EXPOSURE?

Industrial ultrasound devices fall into two broad categories: high power devices and low power devices.

High Power Ultrasound

High power ultrasonic devices are used in cleaning, emulsifying, eroding, extracting, cutting, welding, bonding and drying operations. Most high power equipment operates at frequencies of 20 to 60 kHz. The intensity varies over a wide range. For example ultrasonic cleaning and degreasing devices produce only a few W/cm^2, while metal welding devices produce thousands of W/cm^2. Table 1 lists some of the industrial uses of high power ultrasound sources.

Low Power Ultrasound

The following describes some uses of low-power ultrasonic devices:

- measuring the physical properties and dimensions of objects without causing permanent physical damage (non-destructive testing)
- measuring the flow and physical properties of liquids
- measuring the physical properties of materials and detecting structural flaws (defectoscopy)
- pest control devices and burglar alarms

Table 1 - Uses of high power ultrasound

Use	Frequency (kHz)	Power Output
Cleaning and degreasing parts immersed in solutions.	18 - 100	Usually below 10 W/cm^2; power up to 100 W
Soldering and brazing two surfaces without flux.	Around 30	2 - 200 W/cm^2
Welding soft and rigid plastic.	20 - 60	Usually 20 - 30 W/cm^2; power below 1000 W
Welding similar and dissimilar metals.	10 - 60	Up to 10,000 W/cm^2
Rotary machining, impact grinding with abrasive slurry; vibration-assisted drilling.	Usually 20	
Extracting perfumes, juices, and chemicals from flowers, fruits, plants.	Around 20	About 500 W/cm^2
Atomizing fuel to improve combustion efficiency and reduce pollution; dispersing molten metals.	20-30,000	Up to 800 W
Electroplating, to increase plating rates and produce a denser, more uniform deposit.	Around 27	30 W
Cutting small holes in ceramics, glass and semi-conductors.	Around 20	About 150 W

Source: Repacholi, 1981 (see Further Reading section)

Most low power ultrasonic devices operate at frequencies in the megahertz (MHz) range and produce power densities less than 10 W/cm^2. Pest control devices and burglar alarms operate in the kilohertz (kHz) frequency range.

Table 2 lists some of the industrial uses of low power ultrasound sources.

Table 2 - Uses of low power ultrasound

Use	Frequency
Measuring flow rates for gases, liquids and solids by observing changes in ultrasound frequency.	1 - 10 MHz
Determining elastic properties of materials by measuring speed of ultrasound.	25 - 150 kHz
Determining temperature by measuring changes in attenuation or speed of ultrasound.	Up to 30 MHz
Measuring thickness of materials by timing round trip interval of ultrasound beam.	2 - 10 MHz
Determining pressure by measuring changes in the natural frequency of quartz crystals.	0.5 - 1 MHz
Detecting gas leaks by ultrasonic "noise."	36 - 44 kHz
Measuring levels by observing intensity change and travel time of ultrasound beam.	Around 100 kHz
Detecting flaws by observing discontinuation in reflected beam.	25 kHz to 25 MHz
Detecting intruders by causing reflected ultrasound to activate burglar alarm.	18 - 50 kHz
Controlling pests while being inaudible to people.	18 - 50 kHz
Detecting the presence and velocity of moving objects by observing change in reflected ultrasound.	5 - 50 kHz

Source: Repacholi, 1981 (see Further Reading section)

Tools powered by high speed motors can emit ultrasound in a wide range of frequencies. Such ultrasound is often known as broadband or "white" ultrasound.

Hospitals use ultrasound for making diagnoses, and for performing therapy and surgery. The frequencies of diagnostic devices are in the 1 to 10 MHz range. Devices for eye examinations use higher frequencies. For diagnostic devices, the output power density, when averaged over time, is several milliwatts per square centimeter. But the peak intensities of short duration impulses may reach several hundred watts per square centimeter. The ultrasound intensity from therapeutic and surgical devices is much higher than from diagnostic devices.

5. HOW DOES EXPOSURE TO ULTRASOUND OCCUR?

Exposure to ultrasound can occur through the air or through direct physical contact with the transducer, liquids or solids carrying ultrasound. While exposure to airborne ultrasound is most common, only about 0.1 percent of the airborne ultrasound energy reaching the body surface is capable of entering the inner body tissues. The remainder is reflected back. The ear and hair absorb more ultrasound than other parts of the body. Liquid and solid borne ultrasound can easily enter human tissue through the skin. For example, dipping a hand into an ultrasonic cleaning bath or touching a transducer or an ultrasonicated solid exposes the hand much more than just standing near such devices.

6. HOW DOES ULTRASOUND INTERACT WITH THE BODY?

Ultrasound can cause changes in the human tissue by producing heat, or by causing mechanical disruption or cavitation.

Heating

The body absorbs ultrasound energy and converts it into heat, which raises the tissue temperature.

In contrast to other forms of heating, ultrasound can cause localized heating of the body parts. This is the basis of ultrasonic heat therapy. In industry this effect finds use in ultrasonic welding.

Mechanical Disruption

Ultrasound of sufficiently high intensity can exert a mechanical force causing body tissue to displace, stretch, twist and rupture. This effect finds several types of uses in industry and medicine.

Cavitation

Since ultrasound is made up of mechanical waves, it travels as a sequence of high and low pressure regions. The low pressure cycle can cause bubbles to form in body fluids. These bubbles collapse during the high pressure cycle. This process is known as cavitation. It causes mechanical stress and produces heat.

7. WHAT ARE THE HEALTH EFFECTS OF ULTRASOUND EXPOSURE?

Scientific studies have reported several different effects in animals and biological systems exposed to ultrasound. Animals and people differ in body size, sensitivity to ultrasound, efficiency of energy transfer to the body and exposure conditions. Because of these differences, we cannot use the results of these animal studies to draw definite conclusions about the health effects in people exposed to ultrasound.

Researchers group the health effects of ultrasound in two categories according to the way in which the exposure occurs. These categories are airborne exposure and liquid and solid borne (contact) exposure.

Airborne Ultrasound Exposure

Airborne ultrasound enters the body much more efficiently through the ears than through any other body part. Ears are, as a result, most vulnerable to the effects of ultrasound. Studies of the hearing of industrial workers do not show a link between exposure to ultrasound of pressure levels up to about 110 to 120 dB and either temporary or permanent hearing loss. Some studies show that ultrasound can mask audible sound and impair the hearing sensitivity for sounds of high frequency (above 10 kHz).

Some people working near ultrasound devices report fatigue, headaches, tinnitus (a sensation of ringing or hissing sound in the ears), nausea, irritability, and a "fullness" in the ears. Studies suggest that these effects occur as a result of exposure to audible sound accompanying ultrasound. People with impaired hearing did not report these effects to the same extent as people with normal hearing.

Extremely high levels of ultrasound can cause injury to the body. For example, airborne ultrasound pressure levels of approximately 152 dB can kill rats and guinea pigs by increasing their body temperature. Researchers estimate that whole body exposure to airborne ultrasound pressure levels of more than 180 dB could kill people. This level is far greater than levels likely to occur in the workplace.

Figure 2 summarizes the reported health effects in people and animals from exposure to airborne ultrasound.

Liquid and Solid Borne Ultrasound Exposure

Liquids and some solids can efficiently transfer ultrasound energy to the body tissues. There are risks associated with immersing fingers or hands in ultrasonic cleaning baths, or handling objects that transmit ultrasound with wet or greasy hands. Workers have reported skin irritation and localized skin damage that resembles bruises. Mild effects are reversible and without long-term complications. Some studies also show a link between ultrasound and impaired blood circulation in the hands causing the hands to be numb and more sensitive to cold.

A 1986 Russian study (see Pal'cev et al, Further Reading section) reported the effects of ultrasound on staff who used ultrasonic devices for medical procedures. These effects included disturbances of blood circulation and temperature regulation in their extremities and changes in the bones of their hands. Studies of ultrasonic therapists (see Lundstrom, Further Reading section) have reported diminished vibration sensitivity on the tips of the middle and index fingers.

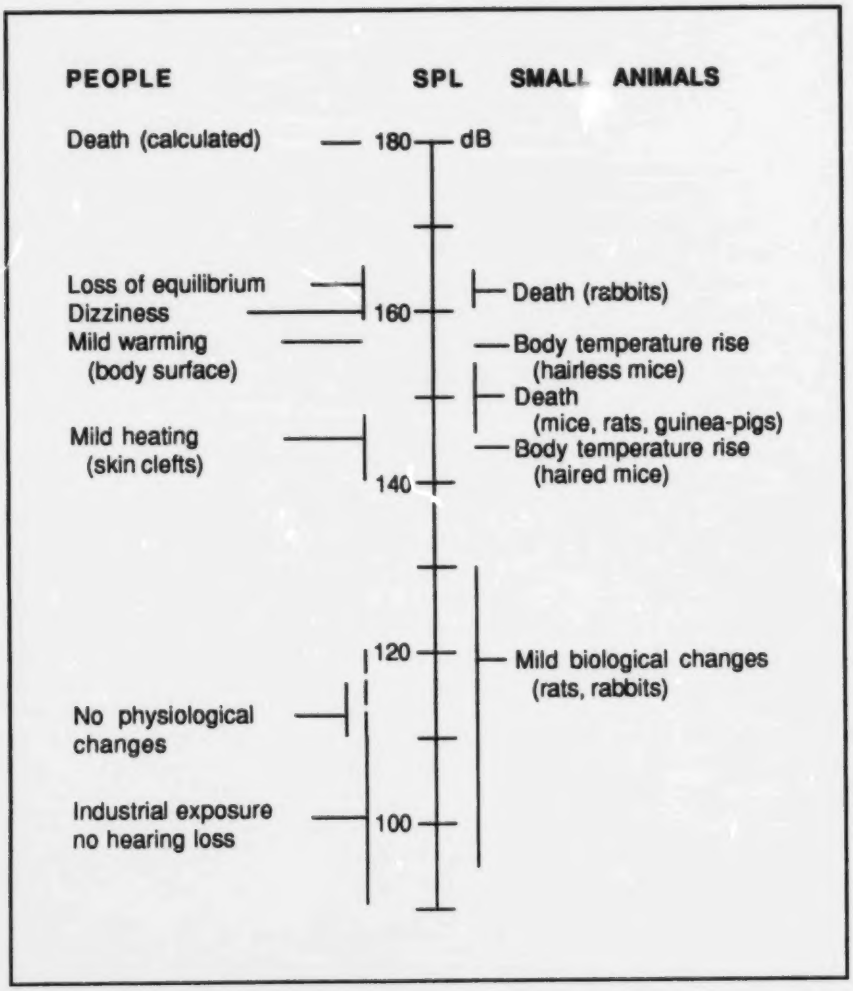


Figure 2 - Biological effects in people and animals from exposure to airborne ultrasound (SPL = Sound Pressure Level)

Source: Acton, 1974 (see Further Reading section)

Effect on Pregnancy

Ultrasound is widely used in medicine to monitor the growth and development of the fetus. Epidemiological studies have not confirmed any health effects due to such exposure.

There are no published reports on the effects of airborne industrial ultrasound on pregnancy.

8. HOW IS ULTRASOUND MEASURED?

Measuring ultrasound is more complicated than measuring workplace noise. Several standards describe methods of field measurement. Refer to Health and Welfare Canada's Safety Codes 23 and 24 or contact CCOHS for further information.

Airborne Ultrasound

Several manufacturers supply special sound level meters that can measure acoustic energy at higher frequencies (20 kHz and above). Such equipment must be able to accurately measure the frequency range of interest. In order to compare with the existing guidelines, the ultrasound pressure level should be measured in dB units for one third octave bands. Measuring ultrasound levels requires certain special precautions. For example, the level may be higher in one particular direction or there could be regions of high and low levels of ultrasound in the area around the source.

Industrial ultrasound sources also produce audible sound. In order to measure the level of audible sound, the sound level meter must incorporate the A-weighting network and a filter which rejects ultrasound frequencies.

Liquid and Solid Borne Ultrasound

Measuring liquid or solid borne ultrasound is far more complicated and imprecise. It is usually not performed in industrial hygiene surveys. Two types of instruments are available--those that measure total power and those that measure power density over small areas.

9. WHAT ARE THE EXPOSURE LIMITS?

Table 3 summarizes the proposed occupational exposure limits for airborne ultrasound from a number of different countries and organizations. In general, these guidelines and standards recommend maximum sound pressure levels from 110 dB to 115 dB for ultrasound frequencies above 20 kHz.

10. HOW IS ULTRASOUND EXPOSURE CONTROLLED?

Since ultrasound is potentially capable of causing harm, workplaces should implement control measures to keep the exposure as far below the recommended limits as possible. The following control measures are suggested:

- Have only trained employees who are knowledgeable about potential harmful effects of exposure to ultrasound, operate ultrasonic equipment.
- Avoid direct contact with ultrasonic transducers.
- Post warning signs in areas that house high power ultrasonic equipment.

Table 3 - Occupational exposure limits for airborne ultrasound
(For total ultrasound exposure exceeding 4 hours per day)

Mid-frequency of one-third octave band (kHz)+	Sound pressure level within one-third octave band							
	Japan (1971)	Acton (1975)	USSR (1975)	USAF* (1976)	Canada (1981)	Sweden (1978)	ACGIH++ (1989)	IRPA** (1984)
8	90	75			80			
10	90	75			80		80	
12.5	90	75	75	85	80		80	
16	90	75	85	85	80		80	
20	110	75	110	85	80	105	105	75
25	110	110	110	85	110	110	110	110
31.5	110	110	110	85	110	115	115	110
40	110	110	110	85	110	115	115	110
50	110		110		110	115	115	110
63								110
80								110
100								110

Updated from: WHO, 1982 (see Further Reading section)

+ Sound level meters can measure ultrasound energy within specified frequency ranges. One-third octave band (1/3 octave band) is a standard method of dividing ultrasound frequencies into such ranges or bands. These bands are identified by their centre frequency and are associated with specified lower and upper frequency limits (band width).

* USAF = United States Air Force

++ ACGIH = American Conference of Governmental Industrial Hygienists

** IRPA = International Radiation Protection Association

- Have only authorized persons, who are trained in methods of minimizing exposure, service ultrasonic equipment.

- Use baffles, absorbers and enclosures to stop ultrasound from reaching a worker. Impenetrable materials readily stop airborne ultrasound.

- Wear gloves lined with material, such as flock or foam, that traps air to provide protection from contact with ultrasound. As the lining material deteriorates, protection diminishes. Avoid direct contact with liquid or solid borne ultrasound.

- Wear ear protection in areas of high intensity airborne ultrasound. Conventional ear protection offers sufficient protection at industrial ultrasound frequencies. Rubber plugs and muffs provide 14 to 20 dB. Foam plugs provide 26 to 32 dB protection because they fit better in the ear canal and leave fewer leakage paths.

- Train employees about safe work practices and the potential hazards of using ultrasonic equipment.

11. SUMMARY

The health effects of industrial high power ultrasound sources are not well documented. Some studies report that workers have experienced a number of health effects such as annoyance, fatigue, and mood changes. These effects may be the result of audible sounds which accompany the actual ultrasound. Ears are particularly sensitive to airborne ultrasound. Conventional hearing protectors provide adequate protection.

Research on the effects of occupational exposure to high intensity ultrasound is inconclusive. Workplaces should take a cautious approach until the hazards of ultrasound are more completely understood. This is particularly true for pregnant women. Employee education is extremely important to ensure awareness of the possible hazards of ultrasound exposure. Engineering controls and safe work practices are the most effective methods of minimizing worker exposures.

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*Presently being updated